Wideband Compact Planar Balun for Applications in Outphasing and Push-Pull Amplifiers

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This letter presents a novel approach to realizing and fabricating a planar balun structure, where conventional bond wires are replaced by conductor bridges supported on polyimide blocks. Three different prototype structures were fabricated on 10 mil thick alumina substrate (er = 9.8, tand = 0.0001) using thin film fabrication technology. Reported, is over a double octave bandwidth from 1.25 GHz to 4.7 GHz with losses lower than 1dB, an amplitude imbalance (trace separation) below 0.75 dB, and phase imbalance within ±5 degrees. Measurements show good agreement with simplified 2D EM simulations. The performance of the balun is assessed for suitability in applications where amplitude and phase balance are of critical importance.

Introduction and motivation: A balun (pontprenau of words balance-unbalance) allows a single-ended, unbalanced ground referenced signals to be transformed into a balanced, differential signal. This property makes the balun an indispensable component in many RF and microwave architectures: filters, mixers, antennas and power amplifiers (PA). However, while realizing baluns at sub-GHz frequencies is fairly straight forward and well documented, the design for higher GHz bands often results in trade-offs between the different figures of merit, thus reaching an octave bandwidth while maintaining amplitude and phase balance can be challenging [1].

This letter describes a balun particularly suitable for the applications in push-pull and outphasing amplifiers, where amplitude balance, here referred as trace separation, is of critical importance and can have detrimental effects on efficiency and linearity of a power amplifier [2]. Previous research at Cardiff University [3] has shown that trace separation can be minimised by adopting a novel balun structure. In this work, that structure is modified for the 1-5 GHz operation, targeting most of the sub-6 GHz telecom frequency bands, while exploring a novel solution for fabricating the structure, which eliminates the use of bond wires.

This work uses the following criteria for determining the bandwidth of the proposed balun; return loss at the un-balanced port < -10dB; losses < 1dB (equivalent to transmission loss > -4dB), along with trace separation less than 0.75dB. Direct comparison to similar work is rather difficult as the design is often tailored to the specific applications. For instance, the authors in [4] use a back-to-back measurement of their structure to determine insertion loss. However, this method cancels out and hides the unwanted trace separation that is crucial in our application. Similarly, the authors of [5] claim the bandwidth of the structure that, when applied within in PA structure, would introduce losses greater than 25% to the overall PA efficiency as transmission parameters fall below -4dB for frequencies greater than 4 GHz. Work presented in [6] and [7] operate in similar frequencies as the balun proposed in this work, however the structures are larger and require greater area due to the different fabrication materials.

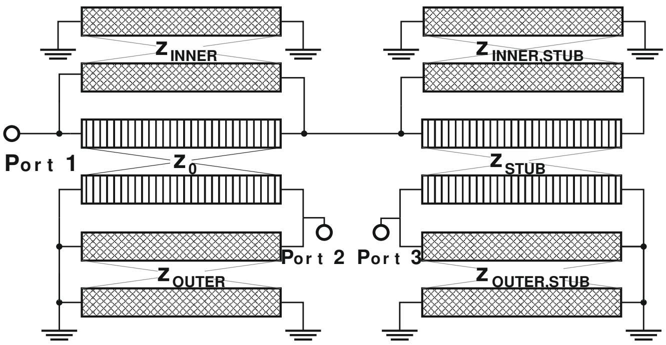

Fig. 1 Simplified *Transmission Line based model of the proposed balun structure*

Design Strategy: The authors of the work presented in [3], introduced a refinement to a balun structure proposed by Marchand. Using the Transmission Line (TL) based balun model shown in Fig.1, which includes effects of the parasitic coupling, the authors derived equations (1) and (2). In this figure two sections of the balun are modelled as two sets of coupled TLs with characteristic impedance denoted as Z_0 and Z_{Stub} and TLs corresponding to parasitic coupling. TLs which are formed between inner conductor and the global ground are denoted as Z_{Inner} and $Z_{Inner,Stub}$, while TLs formed between outer conductor and the global ground are denoted as Z_{Outer} and $Z_{Outer,\ Stub.}$

$$\frac{Z_0}{Z_{inner}} = \frac{Z_{stub}}{Z_{stub,inner}} \tag{1}$$

$$Z_{stub} = \frac{Z_0^2}{2Z_{outer,stub}} \tag{2}$$

Satisfying the ratios in (1) and (2) leads to an improvement in performance of the balun topology that was originally proposed by Marchand [8]. The structure presented in [3] satisfied the above equations by halving the characteristic impedance of the inner conductor in the stub section. This was achieved by creating two transmission lines connected in parallel, as shown in Fig.2 (TLs denoted W5 and W7).

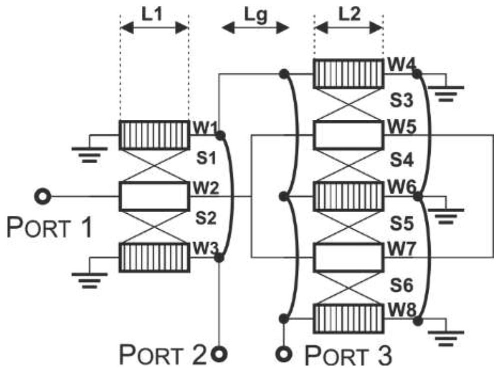

Fig. 2 *Balun structure proposed in this letter.*

The balun presented in this work, shown in Fig. 3 with corresponding dimensions provided in Table 1, satisfies (1) and (2). In this work, differently to what presented in [3], the bond wires were replaced by metal bridges suspended on polyimide support blocks. The polyimide has a permittivity of 3.3 and typical thickness between 3 to 6 µm. The bridges are shown in Fig. 4 compared to the solution realised using bond-wires. The layout of the air-bridge structure benefits from less discontinuities, shown in Fig. 4, which were previously introduced by pads required for reliable bond wiring. Moreover, the new structure has a lower profile and is more robust to mechanical damage.

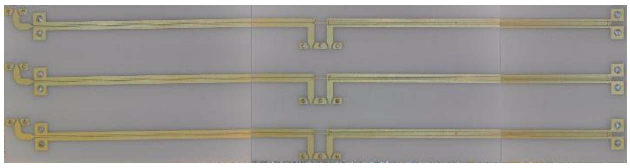

Fig. 3 *Phototograph of balun structures described in this letter*.

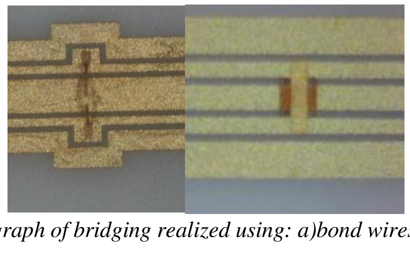

Fig. 4 *Photograph of bridging realized using: a)bond wires b)polyimide bridges*

Two alternative arrangements for the metal bridges were explored in this work: staggered and in-line, as shown in Fig.5. Assessed was the impact of each configuration on performance of the balun. No difference in performance of the balun was observed during measurements.

Table 1: Dimensions of individual elements in the structure described in this letter (Fig. 2).

Name	Value (um)	Name	Value (um)	Name	Value (mm)
W1, W3	125	W6	50	L1	10.75
W2	35	W5,W7	30	L2	11
W4, W8	75	S1–S6	20	Lg	0.5
W5, W7	30				

Characterization Results: Measurements were performed using a 3-port Vector Network Analyser and probe station. The calibration plane was moved to the probe tips using a vendor specific calibration kit. The effects of probe footprints and feed lines were removed by a de-embedding process, using on-board calibration standards. The S-Parameters were acquired in a three port, single-ended configuration, with port designations following the numbering shown in Fig. 3.

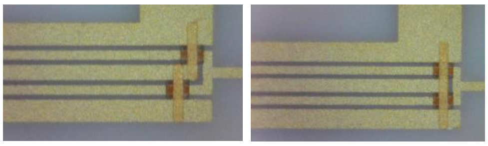

Fig. 5 *Alternative arrangements of the bridging structures used in this work. Staggered (left); In-line (right)*

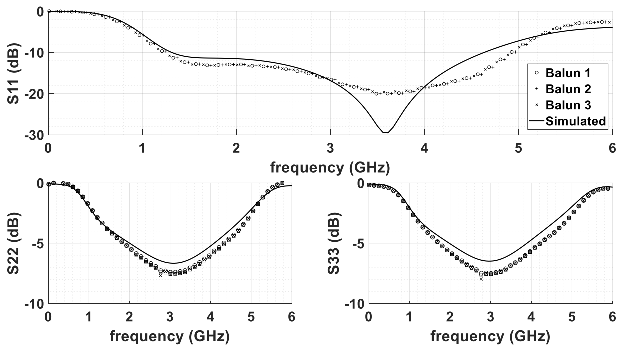

Fig. 6 *Simulated (solid line) and measured (symbols) input return loss at each port.*

Fig. 6 shows the simulated and measured (on 3 samples) input return loss at each port, measured in single-ended 50 Ω termination. The measurements are in very good agreement with the simulations; the main difference is a deeper resonance of S_{11} at around 3.5GHz observed in simulation that does not affect the practical use of the balun. The phase balance, shown in Fig. 7 (top) remains within +/-5° of 175 degrees for frequencies between 0.1 GHz to 5.9 GHz, where a strong resonance was observed. The trace separation, Fig. 7 (bottom), was measured to be less than 1dB for the same frequency band and is in good agreement with simulations, with maximum deviation of less than 0.25dB.

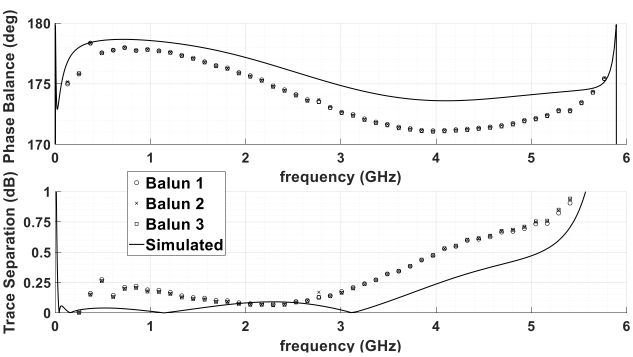

Fig. 7 *Simulated (solid line) and measured (symbols) phase and amplitude balance of differential ports.*

The odd impedance of the balun was measured to be 37Ω for ports 2 and 3, while the even mode impedance for port 1 was measured to be 68Ω. For the S-Parameter measurement environment, these values ideally should be 25Ω and 50Ω respectively. Therefore, further improvements in the performance of this balun structure should be possible by implementing an impedance matching network. No difference was observed in performance between the in-line and staggered bridges solutions.

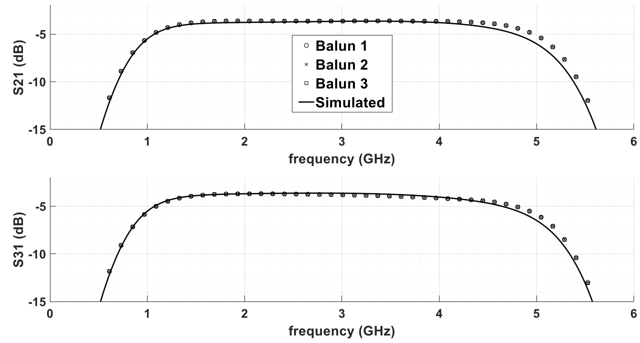

Fig. 8 *Simulated and measured forward transmission parameters.*

Conclusion: This letter presented a 1.25-4.7 GHz balun with low trace separation, making it particularly suitable for PA applications in balanced or outphasing amplifier topologies. A novel method of interconnection, using metal bridges supported by polyimide pillars, is adopted as an alternative to bond wires. The top structure profile was lowered to less than 10 microns and eliminated were the discontinuities created by pads required for bond-wires. The repeatability of the bridging structure was verified across three measured balun samples.

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